FRONTERIES PHYSICS

COSMOLOGY AND PARTICLE PHYSICS

By Nahom Ayele

Cosmology and Particle Physics

Introduction

- **Cosmology:**

The study of the universe’s origin, evolution, and ultimate fate.

- **Particle Physics:**

The branch of physics that studies the fundamental particles and forces of nature.

The Big Bang Theory

- **Overview**: Universe began from a singularity 13.8 billion years ago.
- Evidence:
  - Cosmic Microwave Background (CMB)
  - Redshift of galaxies
  - Abundance of light elements

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Structure of the Universe

- Large-scale Structure: Galaxies, clusters, super clusters.
  - Dark Matter and Dark Energy:
  - Dark matter (27%): Influences Galaxy formation and motion
  - Dark energy (68%): Drives the accelerated expansion of the universe.

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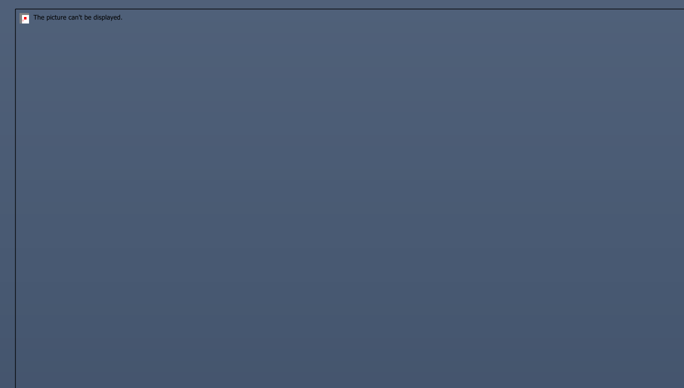
Cosmic Evolution

- Timeline of the Universe:
  - Big Bang → Inflation → Nucleosynthesis → Recombination → Galaxy Formation
- Key Epochs:
  - Inflation: Rapid expansion after the Big Bang
  - Reionization: Formation of the first stars and galaxies

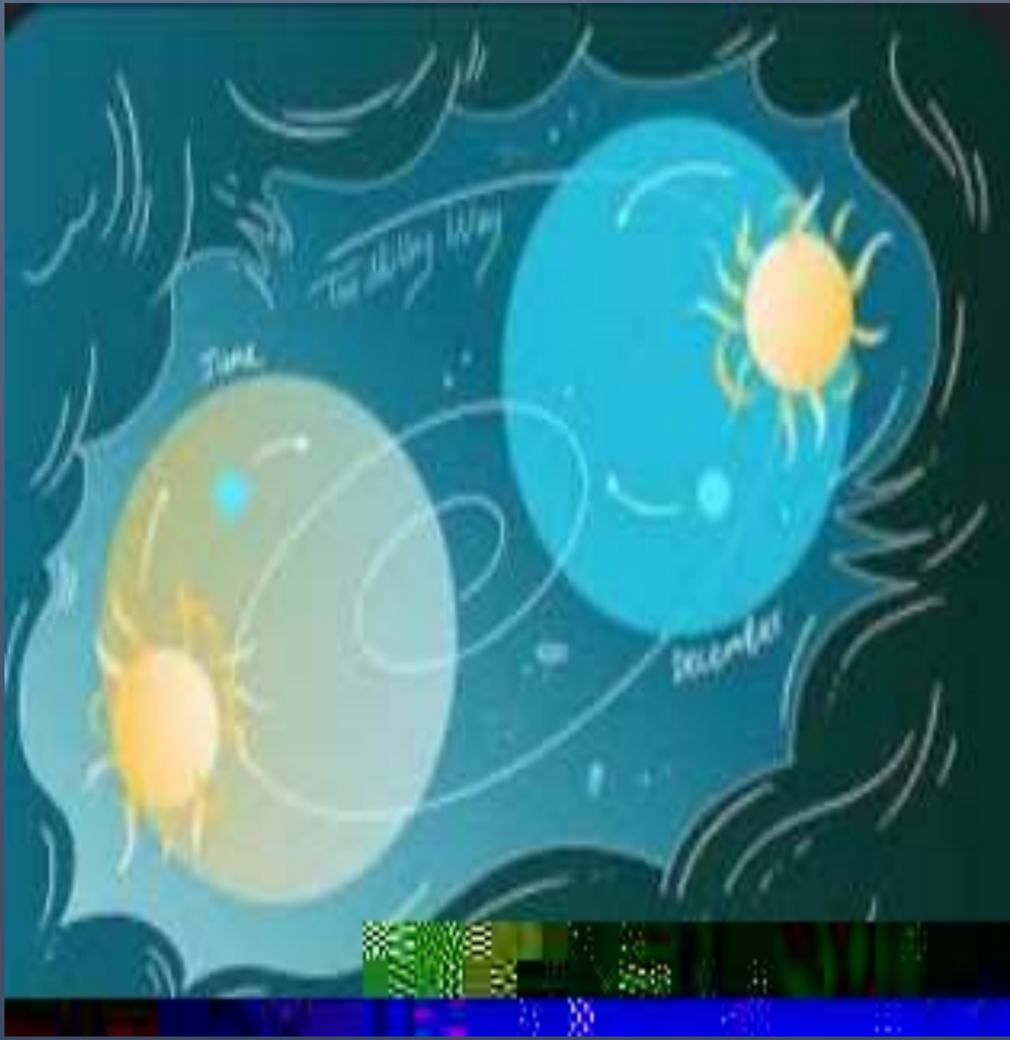


Current Research in Cosmology

- Observations: Hubble Space Telescope, James Webb Space Telescope
- Projects: Planck Satellite, Large Synoptic Survey Telescope (LSST)
- Theoretical Models: Multiverse, cyclic models, quantum gravity

Fundamental Particles and Forces

- The Standard Model:
  - Quarks, leptons, gauge bosons
- Fundamental Forces:
  - Gravitational
  - Electromagnetic
  - Weak
  - Strong



Significant Discoveries in Particle Physics

- Higgs Boson: Discovered in 2012, provides mass to other particles.

- Neutrino Oscillations: Show neutrinos have mass.

- Antiparticles and Antimatter: Existence confirmed through experiments.

Particle Accelerators and Experiments

- Large Hadron Collider (LHC): World's largest and most powerful particle accelerator.

- Notable Experiments:
  - ATLAS
  - CMS
  - Neutrino observatories (e.g., Super-Kamiokande)

Interconnections Between Cosmology and Particle Physics

- Early Universe Physics: High-energy particles and their interactions.

- Cosmic Inflation: Theories based on particle physics.

- Dark Matter and Dark Energy: Possible particle candidates and their role in the universe.

Conclusion

- - Importance: Advances our understanding of the universe and fundamental physics.

- - Future Directions: Upcoming experiments, open questions, and potential breakthroughs.

GENERAL RELATIVITY AND QUANTUM GRAVITY

By Yohanns Getu

SUPERSTRING THEORY

By Tison Teklu

Superstring Theory

Introduction

Superstring theory is a pivotal framework in theoretical physics that proposes all fundamental particles are not point-like dots, but rather tiny, one-dimensional "strings." These strings vibrate at different frequencies, and these vibrations determine the particles' properties. Superstring theory attempts to unify all of the fundamental forces of nature, including gravity, in a single theoretical framework, making it a candidate for the theory of everything (ToE).

Historical Background

The journey of superstring theory began in the late 1960s and early 1970s with attempts to understand the strong nuclear force. The Veneziano amplitude, proposed by Gabriele Veneziano, was a significant early contribution. Later, theorists such as Leonard Susskind, Holger Bech Nielsen, and Yoichiro Nambu recognized that this amplitude could be explained by the dynamics of one-dimensional strings.

Basic Concepts

1. Strings and Vibrations:
In superstring theory, particles are seen as different vibrational modes of strings. The energy and type of vibration determine the particle's properties, such as mass and charge. Strings can be open (with two endpoints) or closed (forming loops).

2. Supersymmetry:

Supersymmetry is a key component of superstring theory. It posits a symmetry between fermions (matter particles) and bosons (force-carrying particles). For every fermion, there is a corresponding boson and vice versa. This symmetry helps in cancelling out certain infinities that arise in quantum field theory, making the theory more mathematically consistent.

3. Extra Dimensions:
Superstring theory requires more than the familiar four dimensions of space and time. It suggests the existence of additional spatial dimensions—six or seven more, making a total of ten or eleven dimensions. These extra dimensions are compactified, meaning they are curled up in such a way that they are not observable at low energies.

Types of Superstring Theories

Superstring theory has five consistent formulations:
1. Type I: Features both open and closed strings with a unique kind of symmetry.
2. Type IIA and Type IIB: These are two types of closed strings with different properties regarding chirality (handedness of the string vibrations).
3. Heterotic SO(32) and Heterotic E8xE8: These theories combine the string theory with another structure known as a gauge group, which governs the interactions of particles

Theoretical Implications

1. Unification of Forces:
One of the primary goals of superstring theory is to unify the four fundamental forces: gravitational, electromagnetic, weak nuclear, and strong nuclear forces. This unification occurs naturally in superstring theory because the vibrational states of strings can represent different force-carrying particles.

2. Quantum Gravity

Superstring theory provides a framework for incorporating quantum mechanics with general relativity, addressing the long-standing challenge of formulating a quantum theory of gravity. The inclusion of the graviton as one of the vibrational states of strings is a critical step in this direction.

3. Dualities

Superstring theory is rich in dualities, which are relationships that connect different string theories and show that they are aspects of the same underlying theory. T-duality and S-duality are prominent examples. These dualities reveal deep insights into the nature of spacetime and the connections between different physical theories.

DARK MATTER AND CLOSURE

By Nahom Girma

What Dark matter?

Dark matter is a mysterious component of the universe that cannot be directly observed. It does not emit, absorb, or reflect light, making it invisible to our telescopes. However, we know it exists because of its gravitational effects on visible matter and the structure of galaxies and galactic clusters.

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Dark matter is estimated to make up about 27% of the composition of the universe. Its presence is inferred from the gravitational effects it exerts on visible matter. Without dark matter, galaxies would not have enough gravitational pull to hold themselves together, and they would fly apart. Paragraph 5:

The exact nature and composition of dark matter remain a mystery. Numerous theories have been proposed, including the possibility of undiscovered particles that interact weakly with normal matter. Scientists are actively conducting experiments and observations to detect and understand dark matter better.

COMPLEXITY AND CHAOS

By Israel Tlahun

WHAT IS COMPLEXITY AND CHAOS?

Complexity and chaos are two intertwined concepts that describe the intricate and often unpredictable behavior of systems composed of many interacting parts. While distinct, they are often found together, shaping the dynamics of natural and social phenomena.

Complexity

Complexity refers to the intricate organization and interconnectedness of a system, where the whole is more than the sum of its parts. It is characterized by:

* Emergence: The emergence of novel properties and behaviors that cannot be predicted from the individual components.

* Self-organization: The ability of a system to organize itself without external intervention, often leading to the formation of intricate patterns and structures.

* Non-linearity: The output of the system is not proportional to the input, making it difficult to predict its behavior.

* Feedback loops: Processes where the output of the system influences its own input, creating a cycle of interaction and adaptation.

Chaos

Chaos describes the unpredictable and sensitive behavior of systems where small changes in initial conditions can lead to drastically different outcomes. It is characterized by:

* Sensitivity to initial conditions: The butterfly effect, where tiny variations in the starting point can lead to vastly different long-term behaviors.
* Long-term unpredictability: Even with perfect knowledge of the initial state, it is impossible to predict the system's behavior with perfect accuracy over extended periods.
* Fractal patterns: The presence of self-similar patterns that repeat at different scales, creating intricate and visually stunning structures.

EXPLORING COMPLEXITY AND CHAOS IN THE REAL WORLD:

These concepts manifest in various real-world systems, influencing their behavior and presenting both challenges and opportunities:

* Weather patterns: Chaotic systems that exhibit unpredictable and complex behavior, making long-term forecasting challenging.
* Financial markets: Complex systems influenced by numerous factors, leading to inherent difficulty in predicting their movements.
* Biological systems: Highly complex systems with emergent properties and self-organizing capabilities, posing challenges for understanding their intricate workings.
* Social systems: Complex systems composed of individuals interacting with each other, leading to emergent behaviors and challenges in managing social dynamics.

Implications for Science, Technology, and Society:

- Understanding complexity and chaos has profound implications for various fields:
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- * Science and technology: It can lead to new scientific discoveries and technological innovations, such as the development of artificial intelligence systems that can learn and adapt to complex environments.
- * Society: Awareness of these concepts can help us better understand and manage social systems, leading to more effective policies and interventions.
- * Managing complexity and chaos: Developing strategies to deal with the challenges posed by these systems, such as implementing adaptive management approaches that can respond to changing conditions.

Complexity

Complexity is a multifaceted concept that describes the intricate organization and interconnectedness of a system, where the whole is more than the sum of its parts. It is characterized by the emergence of novel properties, self-organization, non-linearity, and feedback loops, creating a tapestry of dynamic and unpredictable behavior.

Self-Organization

Self-organization is a remarkable phenomenon where systems spontaneously form order and structure without external intervention. This self-organizing capacity is driven by the interactions between components, leading to the emergence of patterns, hierarchies, and functional organization. Examples of self-organization abound in nature, from the flocking of birds to the formation of galaxies, demonstrating the inherent tendency of complex systems to create order from apparent chaos.

Non-linearity

Non-linearity is a crucial aspect of complexity, where the output of the system is not proportional to the input. This means that small changes in the initial conditions can lead to disproportionately large and unpredictable changes in the system's behavior. The butterfly effect, where the flapping of a butterfly's wings can trigger a hurricane on the other side of the world, exemplifies the sensitivity of complex systems to seemingly insignificant events.

Feedback Loops

Feedback loops are essential elements of complexity, where the output of the system influences its own input, creating a dynamic cycle of interaction and adaptation. These feedback loops can be positive, reinforcing the system's behavior, or negative, providing a mechanism for self-regulation and stability. For instance, the thermostat in a room, which turns on the heater when the temperature falls and turns it off when the temperature rises, is a simple example of a negative feedback loop that maintains a stable temperature.

Conclusion:

Complexity and chaos are fundamental concepts that shape our understanding of the universe and our place within it. By exploring these intricate and fascinating phenomena, we can gain a deeper appreciation for the challenges and opportunities they present, paving the way for a more informed and sustainable future.

HIGH-TEMPERATURE SUPERCONDUCTORS

By Yeabsira Demissew

Introduction

- The concept of superconductors was introduced by Heike Kamerligonnes in 1911.

- The objective is to characterize a material with zero electric resistance .

Conductors and insulators

- Conductors are materials that have electrons (conducting electrons) loosely bonded withe the nucleus or the positive ion of the atoms and the flow when a potential difference created.
- Insulators are materials which don't have conducting electrons to conduct electricity because the electrons where bonded tightly with the nucleus

Conductors and insulators

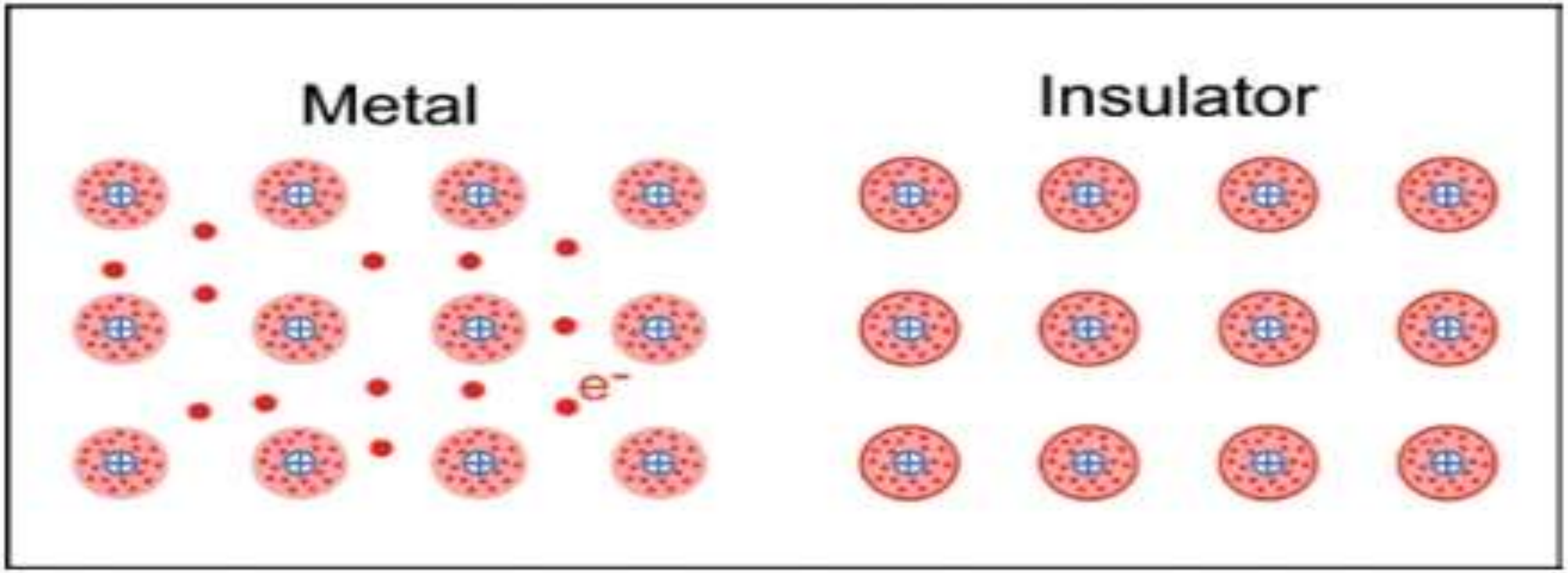
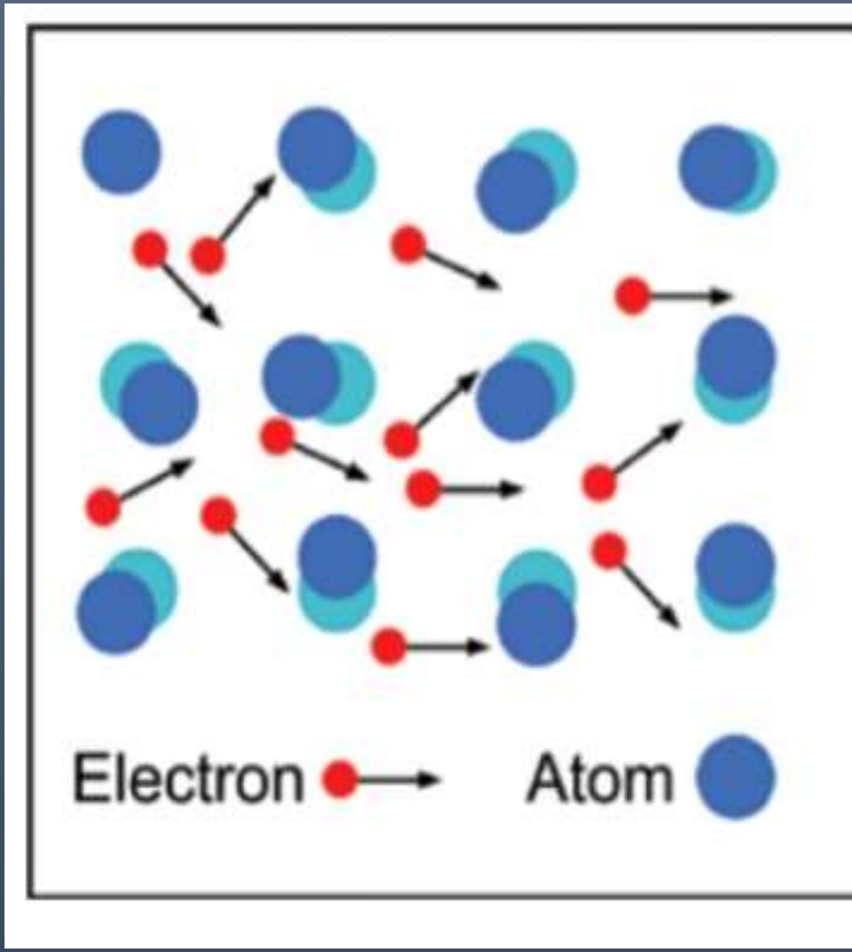


Fig. 1: Schematic representation of a metal (left) and an insulator (right). In the metal the carriers (electrons, small red circles) move almost freely in the matrix of the positive ions, whereas in the insulator they are tightly bound to the ionic core.

Electrical resistance

- Is a resistance on the electric current caused by the random motion of electrons due to the thermal energy they poss.
- The electrical conductance of a material can be characterized by its resistivity ρ which has small values for good conductors (metals) and very large values for bad conductors (insulators) .

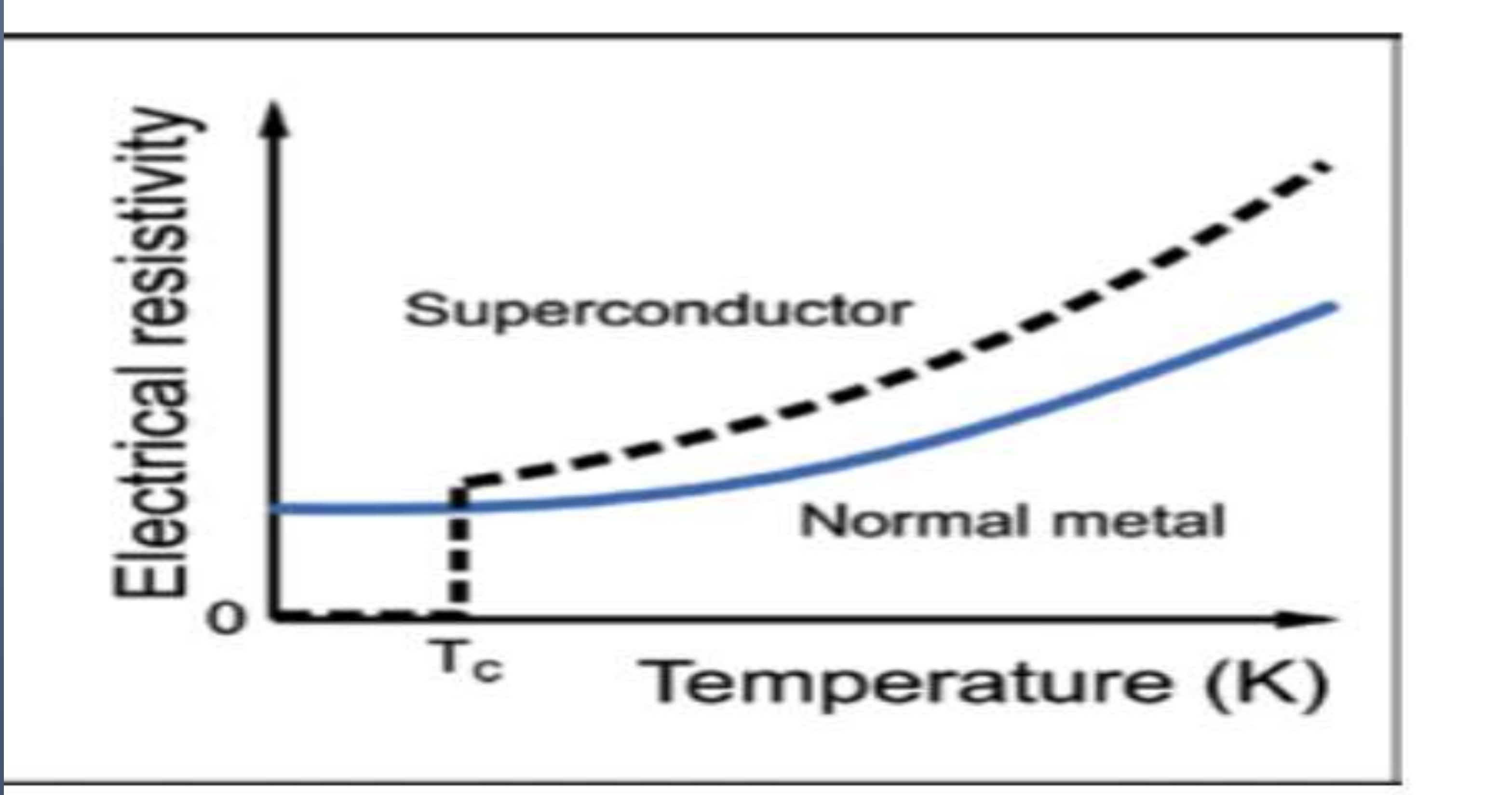


Resistivity of some materials

Materials	metals (M), insulators (I), and superconductors (SC)	ρ (ohm m)
Silver	M	1.6 × 10−8
Copper	M	1.7 × 10−8
Gold	M	2.4 × 10−8
Aluminium	M/SC	2.8 × 10−8
Lead	M/SC	2.2 × 10−7
Mercury	M/SC	9.8 × 10−7
Porcelain	I	5 × 1012
Rubber	I	6 × 1014
Quartz	I	7.5 × 1017

How to solve resistivity of a material ?

- Since this(random) motion of electrons is reduced with decreasing temperature, the resistance is reduced as well and levels off in the low temperature regime.
- The resistivity of the some conductor (superconductor) becomes immeasurably small at the transition temperature (Tc)as shown by the dashed line in the graph below.



- Temperature dependence of the resistivity of a typical metal (solid line) and a superconductor

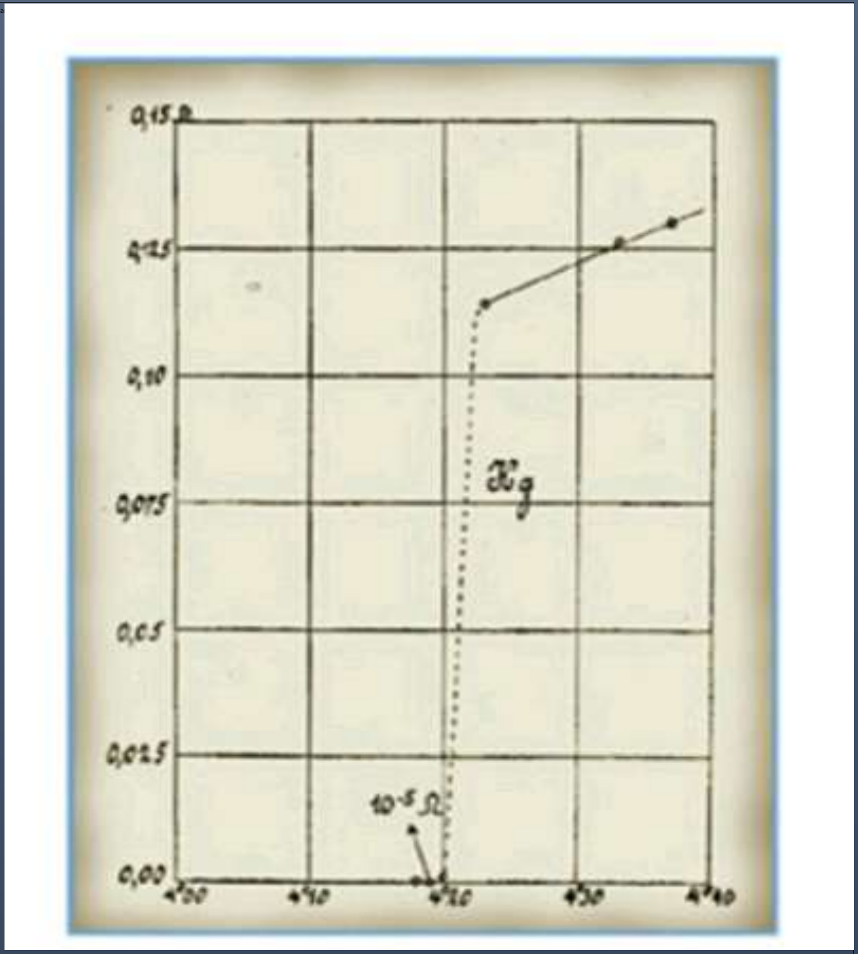
(dashed line).

Superconductivity

- Superconductivity is a set of physical properties observed in certain materials where electrical resistance vanishes and magnetic fields are expelled from the material.
- Material which poses this property are called superconductors.

History of superconductors

- Superconductivity was discovered in 1911 by Kamerlingh Onnes and Holst in mercury at the temperature of liquid helium (4.2 K).



Transition Temperature Tc

- is a temperature at which a substance undergoes some abrupt change in its properties as when it passes from the normal to the superconducting state.

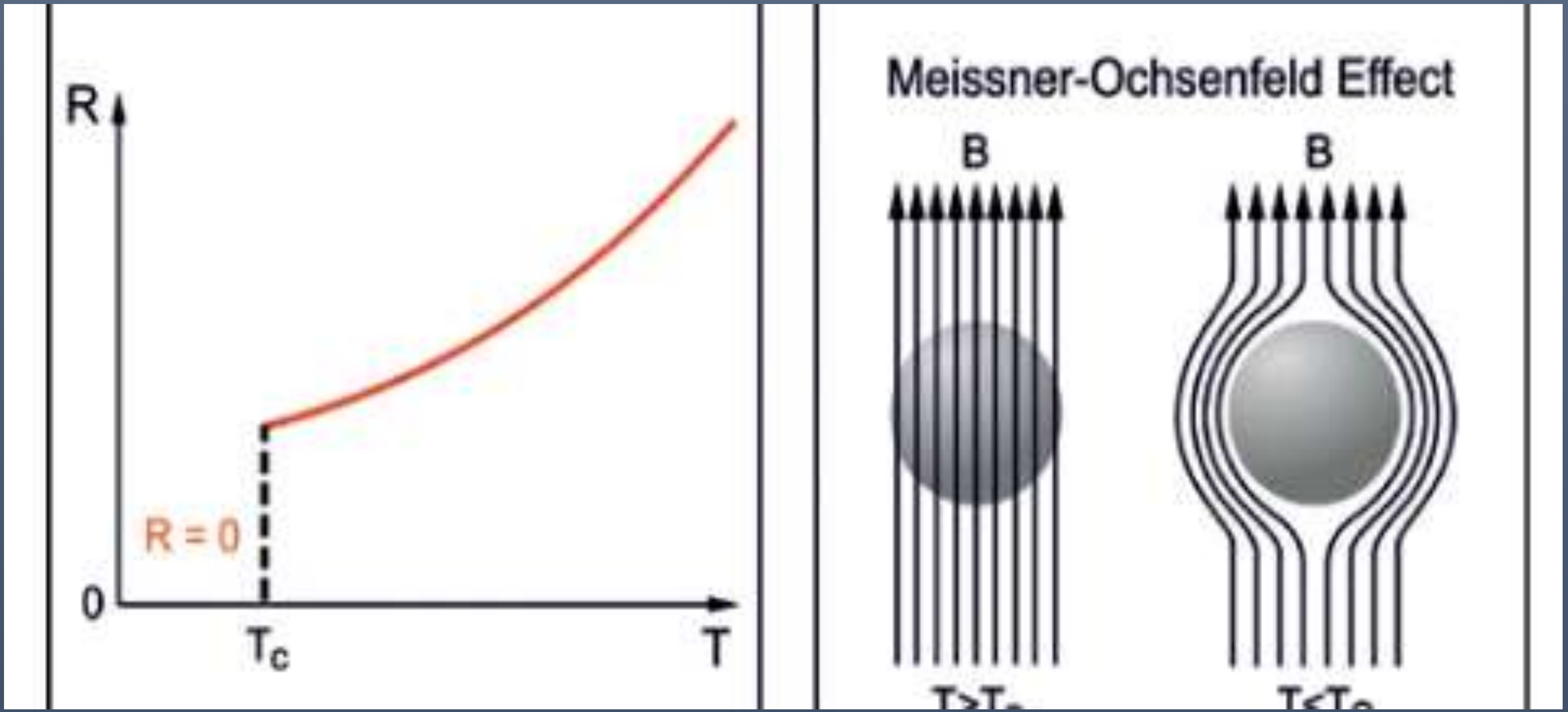
Type of SC	Substance	T_c (K)
Simple metal SC	Al	1.17
	In	3.41
	Hg	4.20
	Sn	3.72
	Pb	7.20
	Nb	9.25
A15 SC	Nb_3Sn	18.0
	Nb_3Ge	23.2
Fullerene SC	$C_{60}Rb_3$	31
Cuprate SC	$La_{2-x}Sr_xCuO_4$	38
	$YBa_2Cu_3O_7$	93
	$Bi_2Sr_2Ca_2Cu_3O_{10}$	107
	$Tl_2Ba_2Ca_2Cu_3O_{10}$	125
	$HgBa_2Ca_2Cu_3O_8$	135
Magnesium diboride SC	MgB_2	39
Iron-based SC	FeSe	8
	$LaO_{0.89}F_{0.11}FeAs$	26
	$Sr_{0.5}Sm_{0.5}FeAsF$	56

Properties of superconductors

(i) perfect conductance and

(ii) the so-called Meissner-Ochsenfeld effect by which a magnetic field is completely expelled from the superconductor, whereas in the normal state it penetrates the superconductor. The Meissner-Ochsenfeld effect is the reason for magnetic levitation.

Properties of superconductors



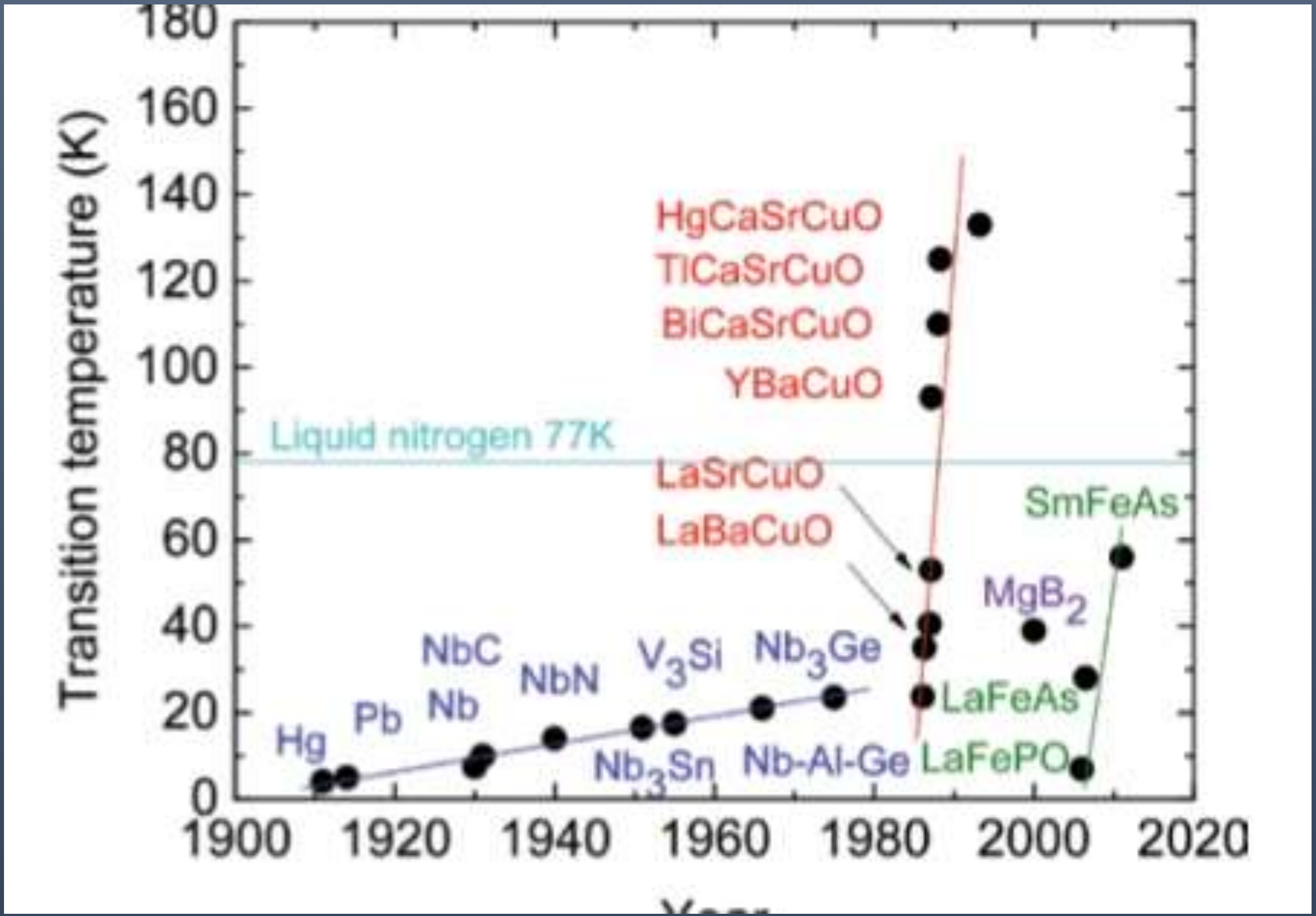
Fundamental properties of a superconductor. (left panel) (i) Zero resistance (perfect conductor). For *T < Tc a superconductor is*a perfect conductor with no resistance. (right panel) (ii) Meissner-Ochsenfeld effect (ideal diamagnet). For temperatures *T > Tc the* magnetic field *B penetrates the superconductor, whereas for T< Tc it* is expelled from the sample.

High Temperature superconductors

- Are materials with critical temperature (the temperature below which the material behaves as a superconductor) above 77 K (−196.2 °C; −321.1 °F), the boiling point of liquid nitrogen.

Examples :-

The development of *Tc with time for conventional and* cuprate superconductors



Applications of superconductores

High-Temperature Superconductors

Electronics
Sensors
Supercomputers
Cryoelectronic Components

Medical Technique
SQUID Diagnostics
Magnetic Resonance Imaging (MRI)

Power Engineering
Generators
Motors
Transformers
Current Limiters
Switchers
Cables
Energy Storages

Basic Research
High-Field Magnets
SQUID Sensors
Bolometers
Particle Detectors

Microwave Technique
Filters
Antenna
Resonators
Delay Lines
Active Components

Traffic Engineering
Magnetic Transport Systems
Ship's Engines
Maglev Trains

OTHER UNANSWERED QUESTIONS IN PHYSICS

By Firol Grima

Here are some unanswered questions in physics:

1. Is there a unifying theory that combines quantum mechanics and general relativity ?

2. What is dark matter and dark energy, which seem to constitute most of the universe's mass and energy?

3. Can we achieve a complete understanding of the nature of black holes, including their behavior at the singularity?

4. What caused the asymmetry between matter and antimatter in the early universe, leading to the predominance of matter?

5. Is there a theory of quantum gravity that reconciles quantum mechanics with the gravitational force?

6. How did the universe begin, and what, if anything, came before the Big Bang?

7. Can we understand the true nature of time and its relationship with space on a fundamental level?

8. What are the ultimate limits of computation and information processing in physical systems?

9. Can we discover new fundamental particles beyond those already known in the Standard Model of particle physics?

10. Are there extra dimensions of space beyond the three spatial dimensions and one time dimension we currently observe?

THANK YOU FOR YOUR ATTENTION